Fully Integrated Full Duplex UWB Wireless Transceiver for Brain Machine-Interface (BMI)

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Top Level Design Overview

- Emerging brain-interfacing technology has a tremendous potential for therapeutic and prosthetic applications.
- We propose a fully wireless brain-machine-interface (BMI) for bidirectional communications with the brain, enabling simultaneous stimulation & telemetry in real time (Fig. 1).
- The system block diagram of the bidirectional biological channel is illustrated in Fig. 2 including the implanted devices, and the external devices.
- Implanted part includes: printed circuit of power coil and antenna, integrated chip, and neural recording and opto-stimulating electrodes (Fig. 3), which is located above the Brain (Fig. 4).

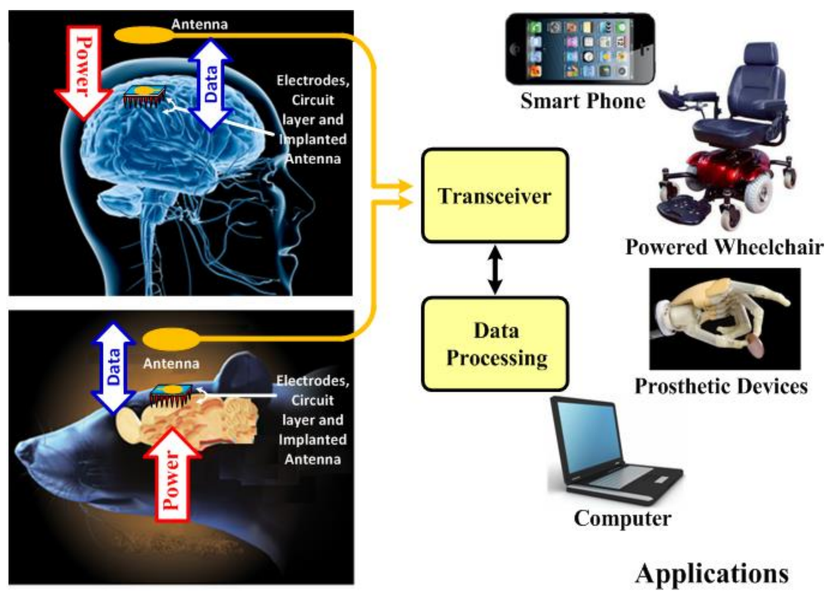

Fig. 1. Brain machine interface applications.

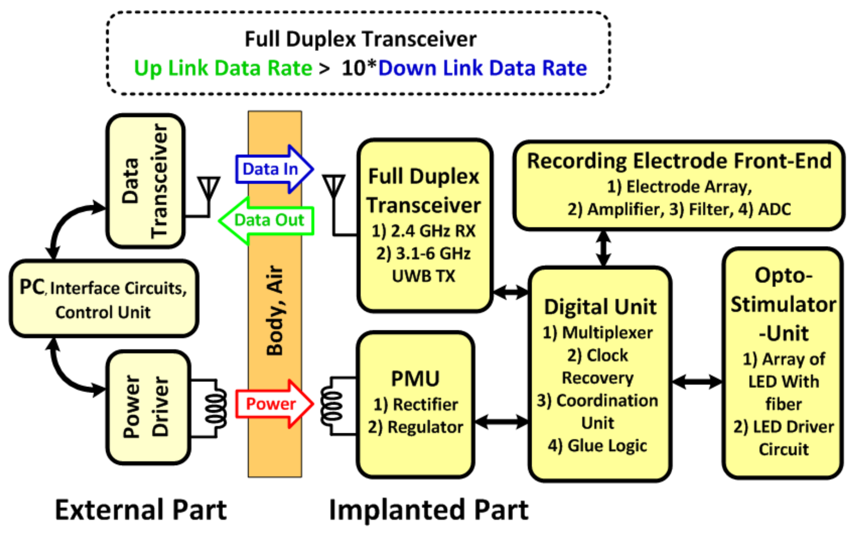

Fig. 2. General block diagram of proposed brain machine interface.

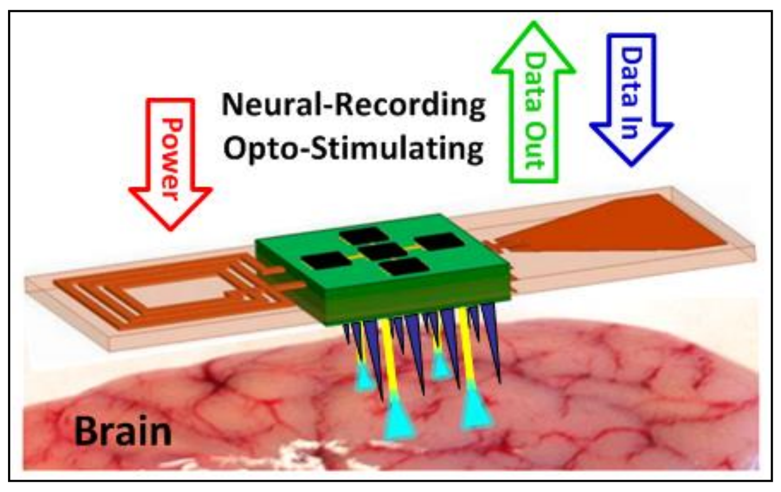

Fig. 4. The schematic of proposed neural recording and stimulating system (implanted side).

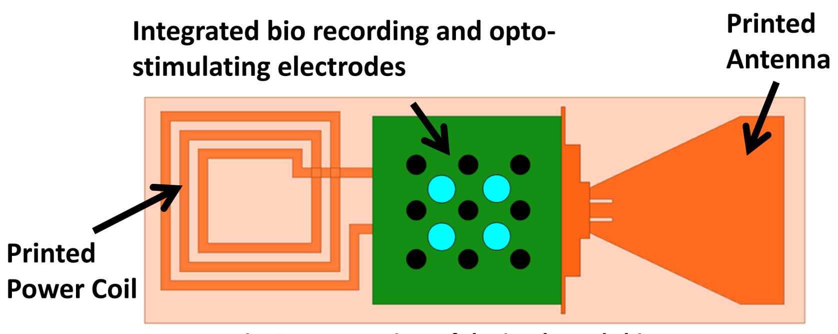

Fig. 3. Bottom view of the implanted chip.

System Level Design

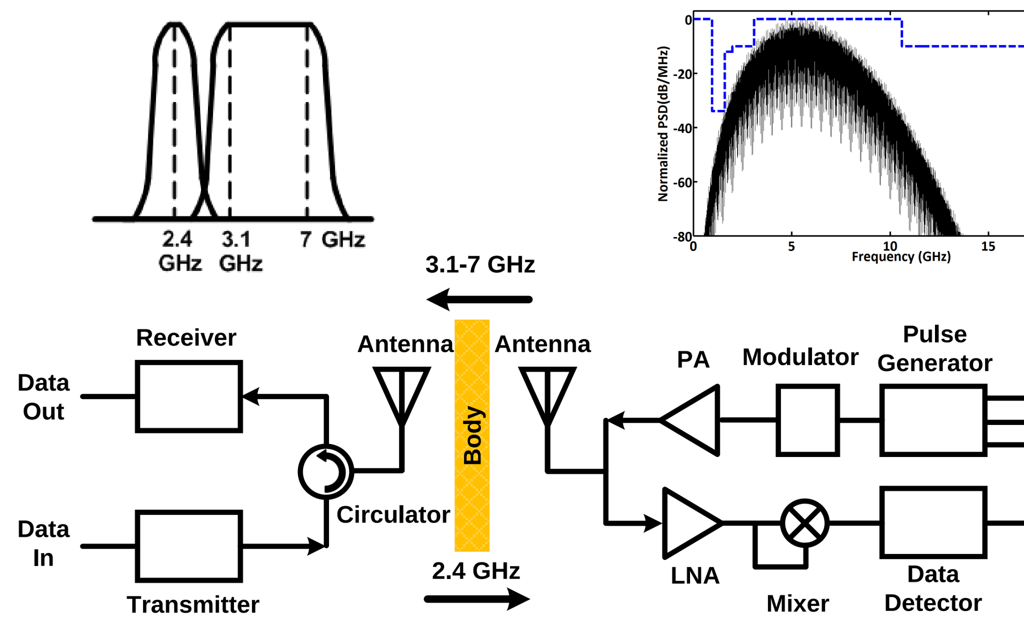

Fig. 8. The block diagram of the proposed full duplex transceiver.

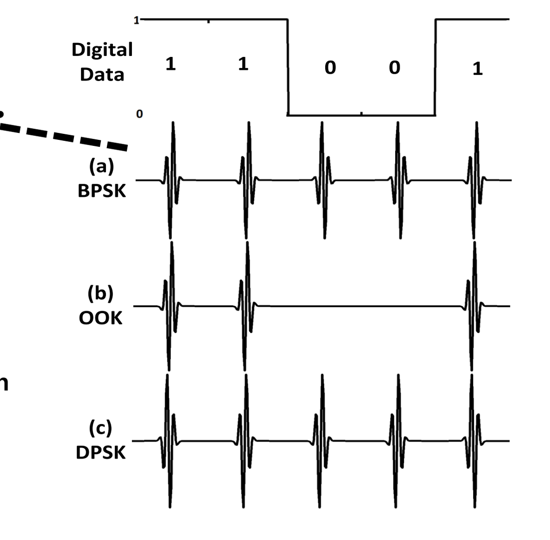

Fig. 9. The modulated waveforms of the transmitter for BPSK, OOK, DPSK modulations.

- A full duplex circulator-less wireless transceiver is proposed to implement high-data rates forward and back telemetry links (Fig. 8).
- Our novel implementation of required circulating feature of a full duplex transceiver is
  1) shaping the transmitted pulse to keep it in the UWB frequency band (3.1-7 GHz).
  2) filtering within the receiver low noise amplifier (LNA).
- Digital data and transmitted waveforms of the implanted transmitter for BPSK, OOK and DPSK modulations are shown in Fig. 9.
- The BER performance of the implanted transmitter is simulated for the modulations through the biological channel with data rates a) 500 Mb/s and b) 2 Gb/s (Fig. 10).

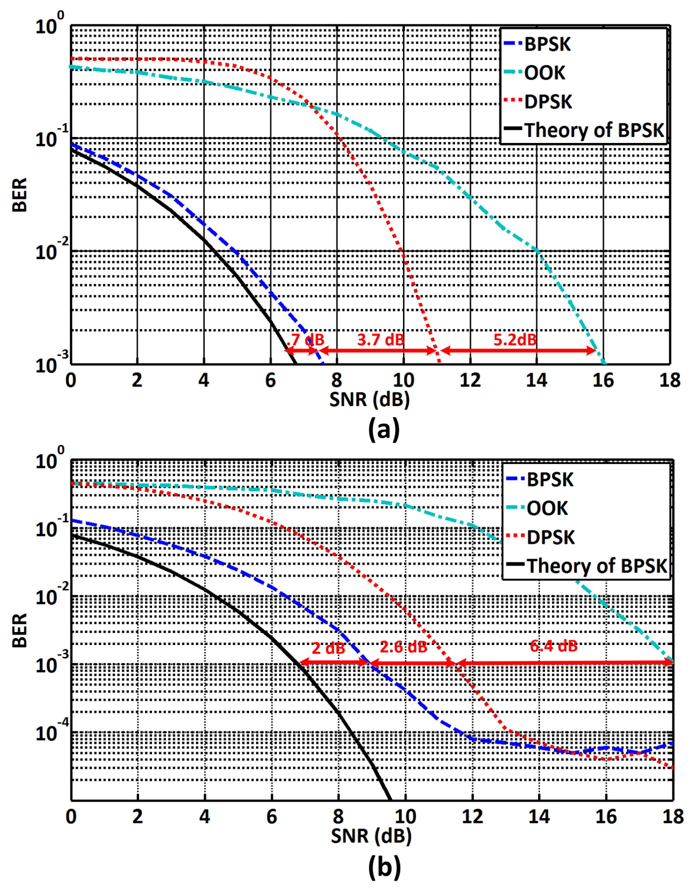

Fig. 10. The BER performances of the three modulations with different data rates a) 500 Mb/s and b) 2Gb/s .

Channel Modeling

- Frequency response of the channe:

$$H(e^{j\omega}) = A(\omega)e^{j\theta(\omega)}$$

- Multi-layer model of head tissue is used for modeling the wireless channel (Fig. 5).
- HFSS software is utilized to simulate the channel.
- Single and dual polarization flexible antennas covering 2-11 GHz (Fig. 6) are designed for implanted side.
- Single and dual polarization antennas are designed for external side (wearable antenna).
- The amplitude and phase of the channel are presented in Fig. 7a) and b).
- The maximum transmitted power by the antennas should be 5.11 mW (3-7GHz) and 12.1 mW (2.4GHz) for implanted and wearable antennas, respectively, to respect ANSI and FCC limitations (Fig. 7c).

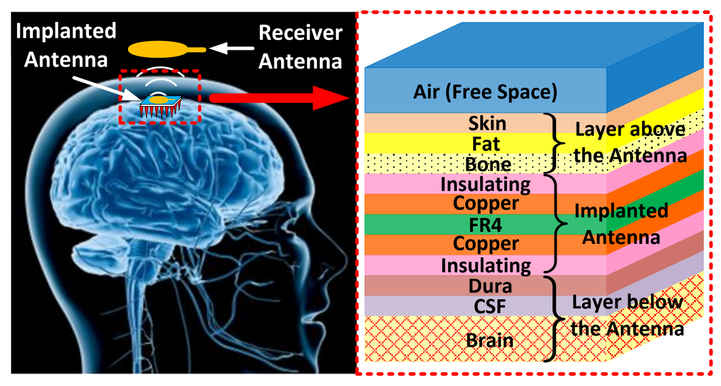

Fig. 5. Multi-layer model of the tissues for the parietal lobe region of the human head used for simulating channel behavior.

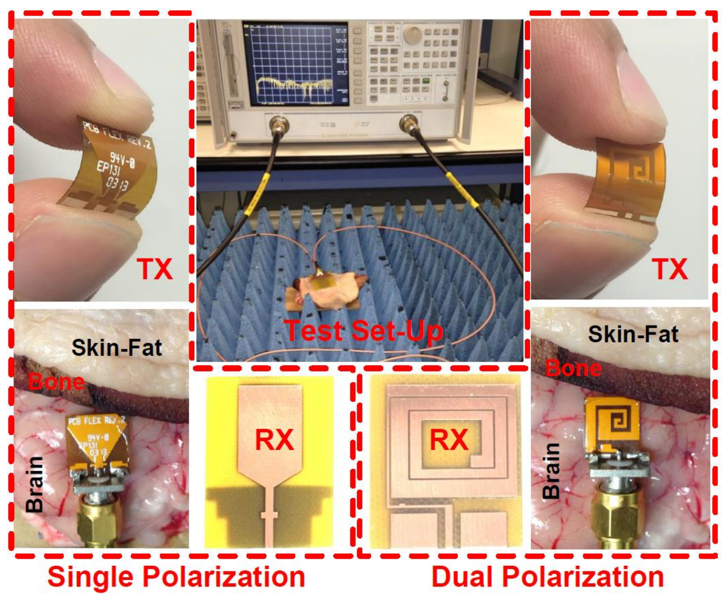

Fig. 6. Test setup for measuring the S-parameter of the single and dual polarization antennas.

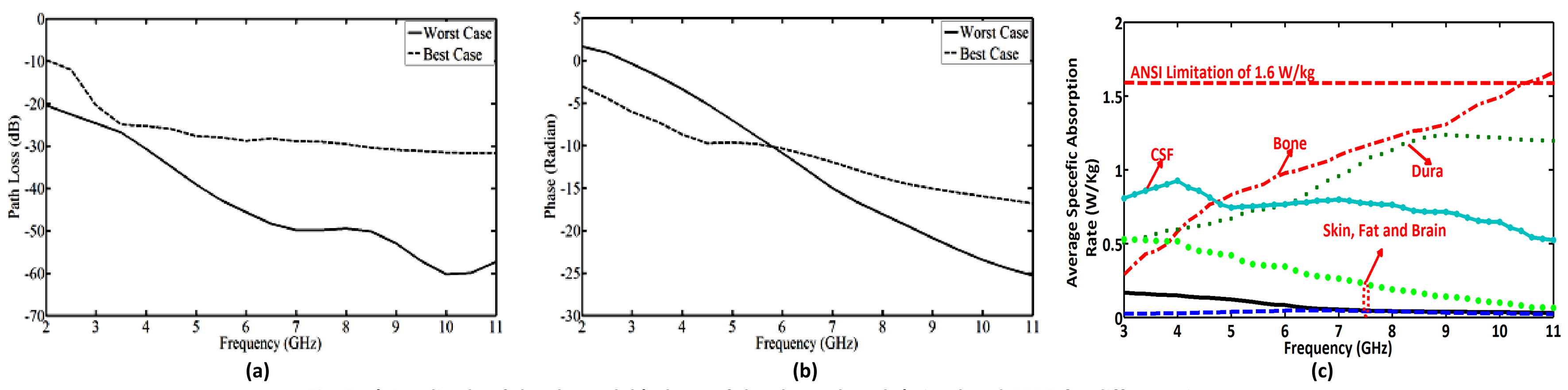

Fig. 7. a) Amplitude of the channel, b) phase of the channel, and c) simulated ASAR for different tissues.

Circuit Level Design

- A fully digital impulse generator is proposed for implementing UWB transmitter (Fig. 11).
- Proposed LNA with feedback structure (Fig. 12a).
- Proposed resistor-less mixer circuit filters the signal and generates proper digital levels (Fig. 12b).
- Chip micrograph is fabricated in 180nm CMOS technology by TSMC (Fig. 13).
- Specifications of proposed full duplex transceiver are summarized in Table I.

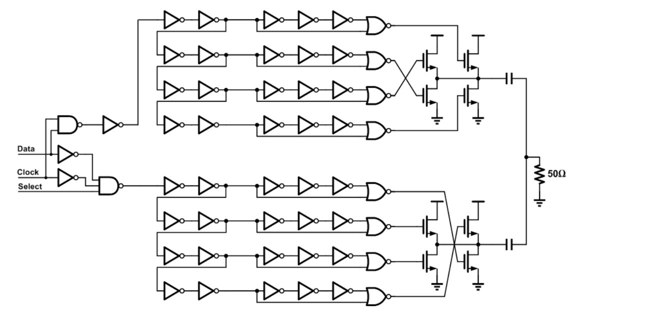
Fig. 11: The UWB transmitter circuit level structure.

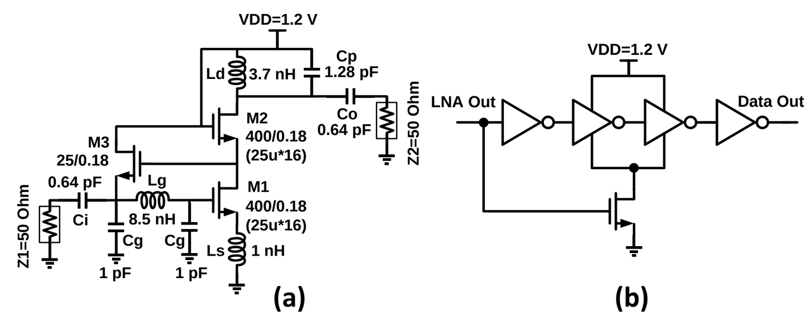

Figure 12: The circuit level of proposed LNA and Mixer as a receiver front-end.

Table I: The specifications of proposed full duplex transceiver.

Transmitter	Values	Receiver	Values
Approach	Edge combining	Approach	Coherent
Bit rate	Up to 2 Gbps	Bit rate	Up to 100 Mbps
Energy (pJ/p)	60	Operating Frequency	2.4 GHz
Frequency band	3.1-7 GHz	Modulation	OOK
Modulation	OOK-BPSK-DPSK	Power Consumption	10 mW
Power Consumption	60 mW	Technology	0.18 µm CMOS
Technology	0.18 µm CMOS	Die size	0.38 mm^2
Die size	0.12 mm^2		

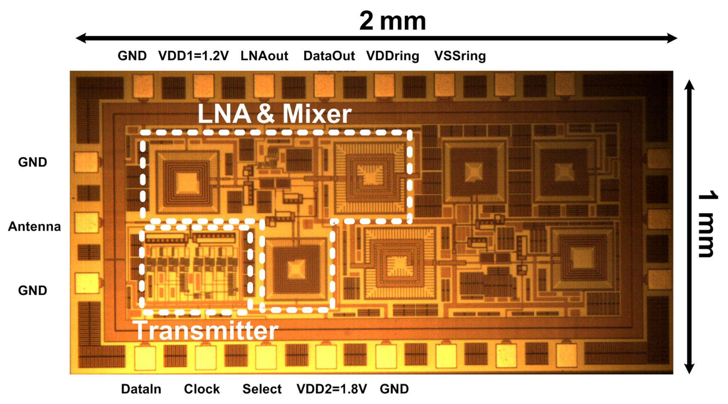

Figure 13: The Chip micrograph (TSMC 180nm CMOS technology) of the proposed full duplex transceiver (0.5 mm^2).

Future Works

- Preparing the required test bench for experimentally testing the proposed fabricated full duplex transceiver chip.
- Characterizing the performance of the full duplex data transceiver through the fresh biological tissues for different modulations and data rates.
- Testing the flexible power coil performance while it wirelessly powers up the transceiver.

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